COMPARISON OF BACK-SCATTERING PROPERTIES OF ELECTRON EMISSION MATERIALS

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Abstract

We use "microscopic" Monte Carlo (MC) simulations, empirical theories, and comparison with experiments to identify the influence of back-scattered electrons and the saturation effect on the emissive properties of materials and to study the gain and transit times for various microchannel plates (MCPs). We have applied this method to Al_2O_3 and MgO emissive materials of various thickness and surface quality. The experimental secondary emission yield (SEY) data were obtained at normal electron impacts and were used as the reference data for adjusting our MC simulations. The SEY data were calculated at oblique angles of the primary electrons in the interval of 0-80°. The energy dependence of backscattered electron coefficients (BSCs) for various primary electron incidence angles was calculated by MC for both materials, and the results were compared with experimental "average" values obtained in the literature. Both SEY and BSC data were used as input files to our "macroscopic" trajectory simulation, which models MCP amplifiers as whole devices and is capable of gain and transit time calculations. The deposition and characterization experiments were conducted for the Large Area Picosecond Photodetector project at Argonne National Laboratory.

INTRODUCTION

Theoretical studies of secondary electron emission yields (SEYs) are necessary as a preliminary step in developing new emissive materials for particle detectors based on microchannel plates (MCPs) in high-energy physics, such as Cherenkov, neutrino, and astroparticle detectors [1,2]. Secondary electrons also play a significant role in the development of new scanning electron microscopes [3–9].

Backscattering, the quasi-elastic reflection of high energy, primary electrons can make a significant contribution to the gain and timing characteristics of MCPs. Yet, this effect is not often accounted for in MCP models.

The goal of this work is to develop a parameterized set of the SEY dependencies in two variables: the energy of the primary electron and the angle of incident electrons (θ), for Al_2O_3 and MgO that are of interest for collaboration in the Large Area Picosecond Photodetector project at Argonne National Laboratory.

This parameterization can be done by using results obtained from Monte Carlo (MC) calculations with existing codes [3–5] modified to meet the needs of MCP developments. The transit times, values, gains, and spatial resolution critical for the new large-area photo-detectors have not been available with the conventional glass MCPs [10]. Therefore, the new MCP concept is based on micron-scale pores fabricated in alumina by the tools developed in the semiconductor industry.

SECONDARY ELECTRON EMISSION AND BACKSCATTERED YIELDS

The calculated SEY data were used as input for a "macroscopic" MCP gain and transit time simulation that computes trajectories of avalanche electrons inside an MCP pore. The feedback from the gain code was used to improve our understanding of the effect of MCP materials on device-level performance and to stimulate further search for better MCP materials.

Secondary electron emission is an important tool for surface microanalysis in various research, science, and industrial areas. Primary electron collisions with the surface of a target generate emissions of various types of secondary electrons [11].

The secondary emission yield (SEY) is the total number, δ, of emitted secondary electrons per primary electron [3]. Table 1 gives the materials constant, ε, the average energy necessary to produce one secondary electron, and the electron escape length, λ, tuned to obtain the best fit of the SEY experimental data for electrons at normal incidence. We obtained the data for Al_2O_3 and MgO by direct MC calculations; the adjustable parameters were obtained from publications [3,5].

Table 1. Material parameters

Material	**ε, eV**	**λ, Å**
Al_2O_3	27.5	20
MgO	20	120

The data for normal incidence, 45° and 80° of the incident angles shown in Fig. 1, were chosen to match the input used by CASCADE, an MCP simulation developed at Arradiance [7]. Our MC simulations of SEY data for Al_2O_3, with the parameters in Table 1, were close to the CASCADE results at normal incidence. However, we did not try to simulate the SEY data at oblique incident angles 10–80° because of the vast choice of simulation parameters to fit. Instead, we used an empirical formula that has an excellent fit for all simulated angles [4]:

$$\delta/\delta_m = 1.11(E/E_m)^{-a}\left[1-\exp\left\{-2.3(E/E_m)^b\right\}\right]$$

where $a = 0.225$ and $b = 1$ were obtained to give the best fit to the CASCADE curves for the angles in the interval of 0–80°. Figure 1 shows a two-dimensional plot of the secondary emission yield generated by primary electrons with energies of $E = 0$–800 eV and incident angles in the range of $0° \le \theta_i \le 80°$ bombarding an Al_2O_3 substrate.

The values of δ_m and E_m at various incidence angles were obtained by a smooth interpolation of the appropriate SEY and E values for the CASCADE yields.

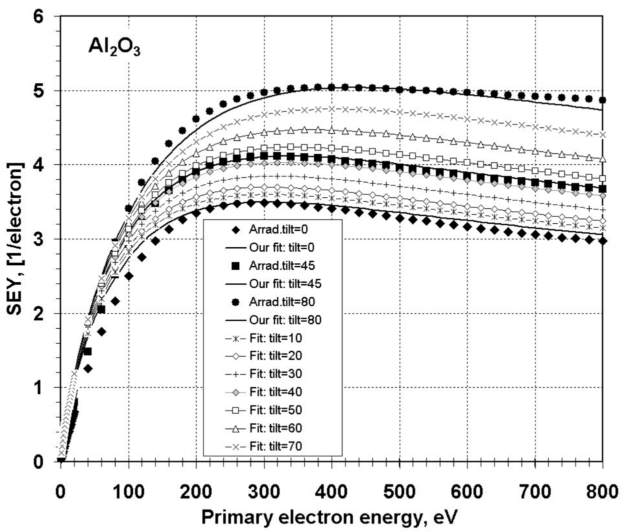

Figure 1. Fitting the secondary emission yields of Al_2O_3 at different primary electron incoming angles.

Figure 2 shows the energy dependence of Al_2O_3 backscattered electron coefficients for oblique electron incoming angles obtained by the CASINO code [7].

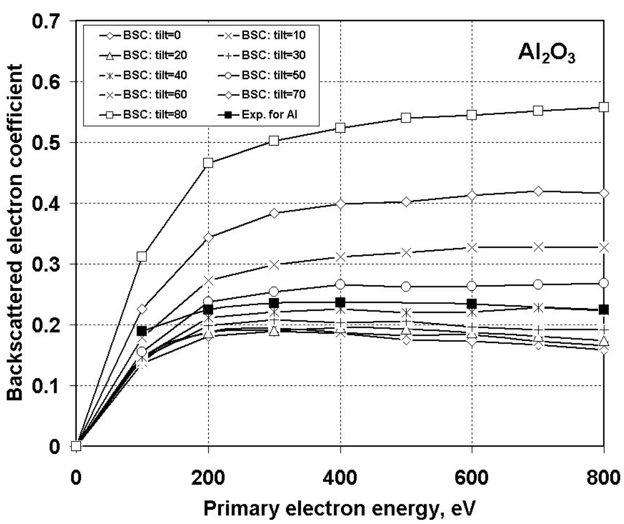

Figure 2. Energy dependence of Al_2O_3 backscattered electron coefficients at different electron incoming angles. Solid symbols are experimental values for pure Al [6].

Figures 3 and 4 show the energy and angular dependences of SEY and backscattered electron coefficients of electrons for MgO at various incident angles in the interval $0 \le \theta_i \le 80°$ simulated by an MC code [3,4].

The parameterized data shown in Figs. 1–4 were then submitted as input data for an MC trajectory code that models the entire MCP device. The results of the whole-device simulations will be published elsewhere.

Since the charging of highly resistive ceramics gives incorrect SEY results, it is important to compare the experimental measurements with the Al_2O_3 emission.

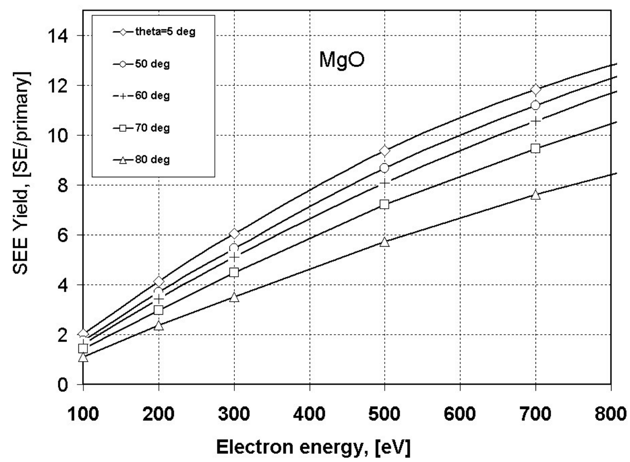

Figure 3. Energy dependence of MgO secondary emission yields calculated by a Monte Carlo method for different primary electron incoming angles and different primary electron energies.

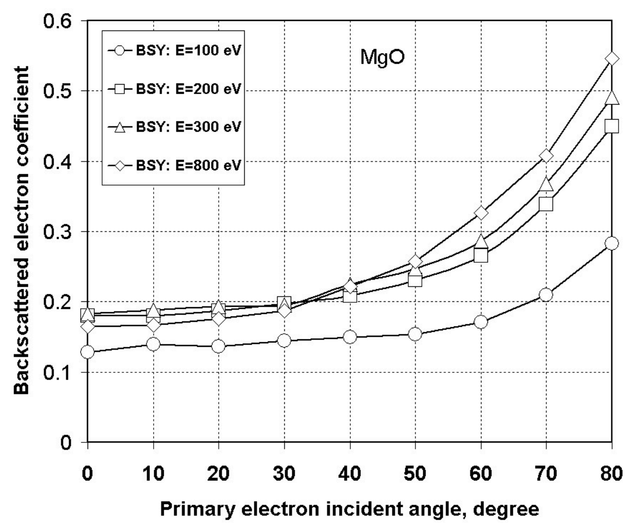

Figure 4. Energy dependence of MgO backscattered electron coefficients at different electron incoming angles.

MCP GAIN AND TRANSIT TIME SIMULATIONS

Here we present the results of numerical simulations using MCS, our Monte Carlo simulator, which takes into account the saturation effect [12], and study the impact of back-scattered electrons. The Monte Carlo simulations were produced for a single MCP of 1.2 mm thickness with 20 μm pores, 8° bias angle, and 1 kV applied voltage. The energy of incoming photo electrons is 350 eV. We calculate the gain factor for each cascade of secondary electrons and arrival time (AT), defined as the time when the MCP pulse crosses 10% of the pulse maximum, for each pulse, and we average those parameters over the number, *N,* of pulses. Table 2 presents the results for true secondary (TS) emission only and for both TS and back-scattering (BS) electrons with different angular bins (ABs) representing the SEY data given in Figs. 1–3. Figure 5 shows the distribution of gains, also known as the "pulse height distribution", for these two cases.

Table 2. Results of numerical simulations

Simulation Code	AB	Gain	AT, ps
MCS, TS	10	21,300	348
MCS, TS+BS	10	60,700	362

These results show that the contribution of the back-scattering electrons should have a significant impact on the total MCP gain and a discernible effect on the transit time of the MCPs. Future studies are needed to compare device-level MCP measurements with MCS simulations for different materials. These studies will help researchers better understand the role of back-scattering and help constrain our models.

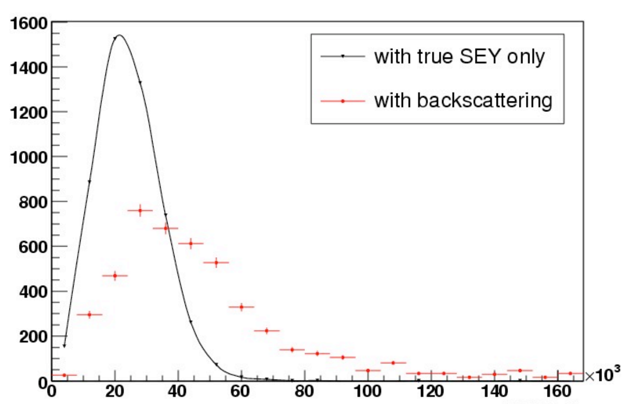

Figure 5. Comparison of pulse-height distributions obtained by the MCS with (red points) and without (smooth line) backscattering model.

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